VITAL-5G: Innovative Network Applications (NetApps) Support over 5G Connectivity for the Transport & Logistics Vertical

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***Abstract*—As 5G networks are being deployed across the world, more and more vertical industries are discovering the benefits of 5G connectivity and the novel business and innovation models that it has to offer. The Transport & Logistics (T&L) industry is expected to be one of the key adopters of 5G technology, where the 5G enterprise market for T&L is estimated to reach $2.9 trillion (€2.7 trillion) by 2026 and grow at a CAGR of 47.5% [1]. However, the adoption and penetration of 5G-based solutions in T&L may be hindered by the knowledge/expertise gap between the vertical industry, the telecommunication experts and the application developers. 5G based Network Applications (NetApps) represent a key enabler for the adoption of 5G solutions, as they can abstract the complexity of the underlying 5G infrastructure for T&L application developers, and significantly reduce the service creation and deployment times, as well as optimize the utilization of 5G resources. The European Innovation Action project VITAL-5G has the vision to advance the offered T&L services by showcasing the benefits of 5G-based NetApps via real-life trials over state of the art vertical (T&L) facilities (warehouse, hubs, ports) and advanced European 5G-testbeds. To support both internal and 3rd-party experimentation, VITAL-5G will create an elaborate experimentation service portal and online repository which will facilitate the creation, deployment, monitoring and (re)configuration of NetApps in the vertical environment.**

Keywords—Transport, Logistics; NetApps; 5G-testbed; vertical experimentation; port/warehouse trials; SME;

I. INTRODUCTION

The Transport and Logistics (T&L) vertical is a major component of modern production and distribution systems and a key contributor to macroeconomic development, accounting for over 10% of Gross National Product (GNP) in most countries [2]. As 5G delivers new capabilities to vertical stakeholders (such as support of thousands of distributed devices, extreme reliability and low-latency, extreme throughput), substantial commercial and innovation potential exists for software developers to provide new and innovative 5G-empowered applications for the T&L sector.

The strategic objective of the European Innovation Action project VITAL-5G [3] (Vertical Innovations in Transport And Logistics over 5G experimentation facilities), which started in January 2021, is to create an open, virtualized and flexible experimentation facility comprised of an intelligent virtual platform, three distributed European 5G-testbeds (Antwerp, Athens and Galati (Danube)) and associated vertical infrastructure, to enable the testing and validation of T&L Network Applications (NetApps) in real-life conditions, utilizing 5G connectivity. VITAL-5G engages significant logistics stakeholders (Sea/River port authorities, road logistics operators, warehouse/hub logistic operators, etc.), Mobile Network Operators (MNOs), and innovative SME experimenters, thus focusing on multi-modality and addressing challenges of the entire 5G-enabled T&L ecosystem.

This paper provides an overview of the VITAL-5G project, which will build on top of the knowledge, expertise and infrastructure (e.g., 5G-testbeds, AI/ML mechanisms, etc.) provided by predecessor European projects, such as 5G-EVE [4], 5G-BLUEPRINT [5] and 5G-SOLUTIONS [6], allowing it to focus on the development of added-value components and concepts such as the design and validation of innovative Vertical T&L NetApps, their association with an open repository and the instantiation of a service orchestration platform to help accelerate the growth, adoption and economic benefits in 5G exploitation for the European T&L sector. The concept of NetApps, which will be introduced and fostered by VITAL-5G, will enable experimenters to experience ultra-fast service creation, dynamic customization of the service, flexible adjustment to real-time conditions and more.

The remainder of this paper is organized as follows. Section II presents the VITAL-5G concept and the envisioned system architecture. Section III provides the description of the VITAL-5G experimentation facilities and their associated T&L use cases for performance evaluation purposes, while Section IV provides an overview of the project's targeted innovations, ambitions and commercialization approach. Section V concludes the paper.

II. VITAL-5G CONCEPT & SYSTEM ARCHITECTURE

A. VITAL-5G Concept: An integrated platform

The VITAL-5G platform provides a rich set of flexible and intuitive tools and APIs to facilitate the design, management, orchestration and validation of virtual services for various vertical sectors in the pan-European T&L eco-system. The platform allows to share and compose production-ready NetApps, made available by multiple providers in an open repository, to build end-to-end T&L services for trials and validation over 5G network slices.

VITAL-5G offers an open framework for experimental testing and validation in 5G virtual environments, which are dynamically built and configured over a facility comprising three T&L trial testbeds involving respectively a sea port, a river port and a warehouse/hub, as described in Section III.A-C. The operation of these facilities is unified through an integrated platform exposing an online, centralized portal where various T&L stakeholders can evaluate and benchmark the performance of novel NetApps in the T&L area, deployed on top of configurable 5G networks.

The integrated and network-abstracted nature of the VITAL-5G platform lowers the barriers for T&L affiliated verticals, which are usually missing a specific expertise on 5G networks, to deliver 5G-enabled services in an effective and simplified manner while exploiting all the benefits of 5G technologies. The virtualized 5G infrastructures with embedded resource control, orchestration and management offer the possibility to deploy complex services in short time, applying the latest virtualization techniques and with the flexibility to customize allocated resources and mobile connectivity on the basis of the specific T&L service requirements. In fact, VITAL-5G trials run over dedicated and custom network slices, in secure and trusted environments that give the opportunity to validate T&L NetApps in a variety of operational contexts, fundamental to tune the application parameters before launching the service on the market. Using the embedded composition tools, T&L service providers can mix network functions, vertical-specific and vertical-agnostic NetApps from a wide and open catalogue, creating multi-provider service chains. In this context, the automated execution of test cases and the collection of metrics and KPIs at the network and NetApps level simplify the technical validation of the end-to-end services and the evaluation of associated business values.

B. VITAL-5G facility: distributed testbeds and open platform

The VITAL-5G architecture, shown in Figure 1, is structured in two major layers: the 5G-enabled T&L testbeds distributed in three European countries and the cross-facility VITAL-5G open platform that implements all the tools and services for design, on-boarding, deployment, orchestration, monitoring, validation and diagnostics applied to T&L vertical services. The open platform consists of an Online Portal for experimental validation and an Open Online Repository for NetApps and Virtual Network Functions (VNFs) (see Section II.C). Software providers can design their own virtual applications and on-board their packages and images in the VITAL-5G Repository, making them available as building blocks for more complex T&L services. The Portal tools allows to validate the single NetApps in different target environments and to easily compose them into T&L service blueprints for verticals and third-party service providers.

The VITAL-5G Portal offers a web graphical interface and programmable REST APIs to manage the creation, instantiation, Life-Cycle Management (LCM) and monitoring of T&L services and related 5G network slices. These procedures are facilitated through an intent-based interface that provides abstraction of the service description and transforms autonomously the application-driven service intents into 5G/NFV service descriptions and LCM actions.

At its southbound, the Portal interacts with the local NFV MANO and NG-RAN control systems available at the three trial facilities. The primitive actions of network slice creation, resource instantiation and monitoring data collection are coordinated at the Portal level in a unified manner and executed in each site using the specific orchestrators, monitoring platforms and network controllers deployed at the facility. In this respect, the VITAL-5G Portal serves also as an abstraction and aggregation layer across different domains of a 5G facility (5G RAN, edge/core based on NFV MANO).

The VITAL-5G Portal constitutes also the centralized access point to manage the experimental testing and validation of the T&L services. In this direction, it integrates a full suite of tools to build virtualized test environment, automate the execution of test cases, collect and validate KPIs, and perform a diagnostic analysis on the experiment results. The KPI validation tools for service performance evaluation and benchmarking are designed to enable the automated verification of business SLAs and act as triggers for service automation and self-management, specifically tailored for the T&L vertical requirements.

The Open Online Repository manages onboarding procedures for the NetApp packages in the Vital-5G platform. A catalogue service implements programmable APIs and a web-based graphical front-end to onboard, query, retrieve and update packages of VNFs and virtual applications, Network Slice templates [7] and Network Service descriptors [8], service and experiment blueprints [9], etc. The service also implements Role Based Access Control (RBAC) and possibly Attribute Based Access Control (ABAC) to regulate access, view, and actions permitted on NetApp packages, integrating further mechanisms for e-Licensing management. User profiles and additional policies can be employed to regulate both user actions on the repository and the subsequent onboarding to the target trial facility.

C. VITAL-5G NetApps concept

One of the major objectives of the VITAL-5G platform is to abstract the complexity of 5G/NFV service descriptors for application developers in order to simplify service deployment for the T&L sector. This is accomplished through the concept of Network Applications (NetApps), virtual applications that are built and distributed through self-contained packages comprising their virtual images and metadata, descriptors and scripts that simplify their composition in service chains formed by virtualized and physical functions, as depicted in Figure 2.

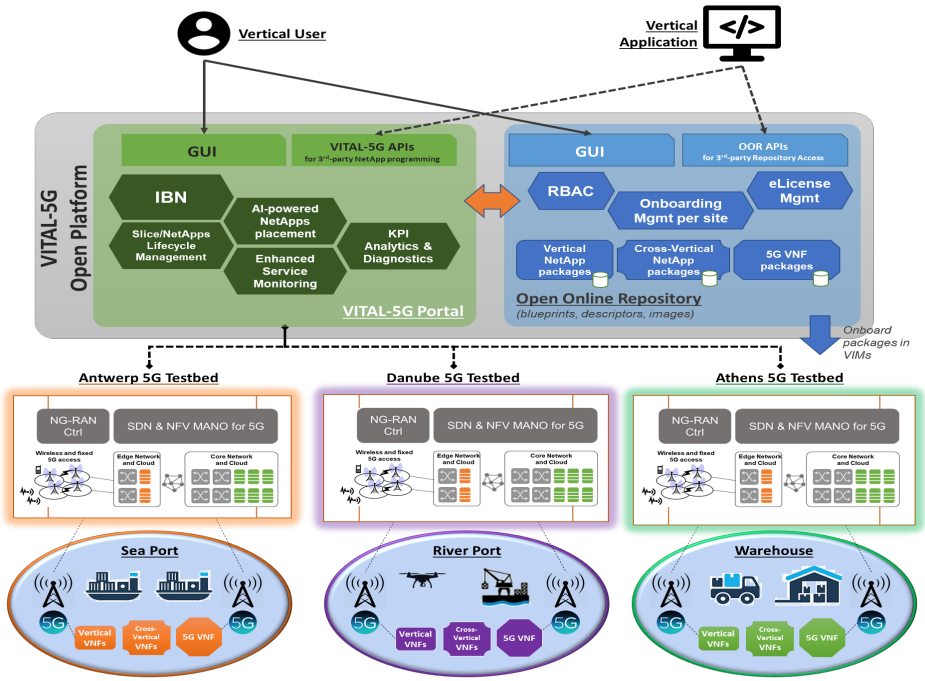

Figure 1: VITAL-5G architecture

VITAL-5G NetApps are divided into two categories, vertical-agnostic NetApps (grey boxes in Figure 2) and vertical-specific NetApps (green boxes in Figure 2). They can be combined together, and/or with generalized network functions in the form of VNF or PNF (shown as yellow boxes in Figure 2) to deliver end-to-end T&L services.

Vertical agnostic NetApps are used to implement core primitives for data processing at the application layer, e.g., database, IoT event bus, generic monitoring agent, etc. They include functionalities that can be used in a variety of vertical applications and T&L services. An example of vertical-agnostic NetApp could be an IoT Management Platform, used for generic IoT device management, monitoring, and report generation, independently on the specific sensors and actuators, data models and message protocols adopted in a given facility with its own IoT infrastructure deployment.

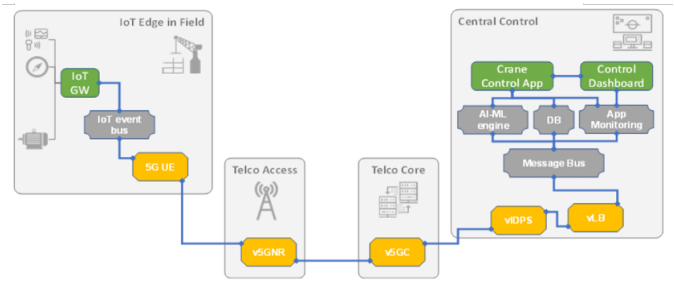

Figure 2: VITAL-5G NetApp concept

Vertical specific NetApps address specific industry challenges for the T&L sector. They can be specific to the connectivity layer implemented at the target T&L premises, e.g., an IoT gateway for reading sensors and controlling devices, storing and analyzing data in a specific control application, an image processing engine, etc. An example in this category is the 'Autonomous Vessel Navigation Control' which makes use of a digital twin, monitoring sensor data, obstacle detection and tracking, and path prediction for the autonomous control of a vessel.

III. T&L USE CASES AND INFRASTRUCTURE ENABLERS

This section presents the VITAL-5G experimentation facilities, comprised of the respective 5G-tetbeds and vertical infrastructure, as well as the use cases (UC) that will be evaluated in each of them, respectively.

A. Automated vessel transport - Antwerp facility

This UC will be validated over the Antwerp 5G testbed located at the port of Antwerp, Belgium. The testbed is based on i) infrastructure of Telenet's (Belgian MNO) Innovation Centre, ii) connectivity, infrastructure and system built for the 5G-Blueprint project [5] and iii) connectivity and supporting infrastructure built for Telenet's 5G commercial launch in Flanders. The complete system will provide a fully standalone (SA) 5G network supporting 3GPP Rel.16 and will be further comprised from a virtualized 5G Core, Multi-Access Edge Computing (MEC) nodes and multiple end devices, supporting end-to-end slicing.

The aim of this UC is not only to remotely control semi-autonomous vessels, but also doing it within a mission-critical environment such as the Port of Antwerp. 5G connectivity and networking slices techniques will deliver reliable and flexible connectivity while assuring coverage and functionality. Moreover, in order to enable such teleoperation of vessels at the port area, machine learning techniques are used to optimize the route planning following the berthing time slots set by the Port authorities and Terminal operators. In technical terms, HD camera feeds and sensor data are sent in real-time from the vessels to the command center, and real-time steering

commands are sent back to the remote vessel. In logistic terms, it is mandatory to have two captains onboard, and before this can be reduced to 1 or even 0 persons onboard, guarantees relative to both reliability and redundancy are required. As connectivity is currently a main bottleneck, 5G will be able to fulfil these challenging requirements (bandwidth, latency, throughput, etc.). A real-time digital twin will be built around the vessel to support the remotely controlled (and later on autonomous) vessels. In parallel, real-time route is foreseen to optimize the port operations and to avoid idle times, aligning to the Port authorities scheduling slots.

The challenges that this UC focuses on are: 1) Remotely controlled and (semi-)autonomous navigation to reduce the number of onboard personnel, allowing one operator to remotely control more than one vessel, increasing productivity. Four NetApps will be combined (e.g. Remote vessel navigation and Autonomous vessel navigation control NetApps, combined with On board data collection interfacing for vessels NetApp, and assisted by Navigation Speed Optimizer NetApps) to select and foresee the best paths in the dock to minimize berthing time, 2) Navigation speed optimization schedules and speeds are built based on past, current and future status of port assets, avoiding vessels to wait unnecessarily while berths are in contention (i.e. Navigation Speed Optimizer NetApp), and 3) Real-time port control - simulating a Digital Twin of the port to assist in real-time port control and to foresee short-term future port status (i.e. Real-time Digital Twin NetApp, combined with the On board data collection & interfacing for vessels NetApp). Figure 3 illustrates the context (site) and the functionality (NetApps) involved in this UC.

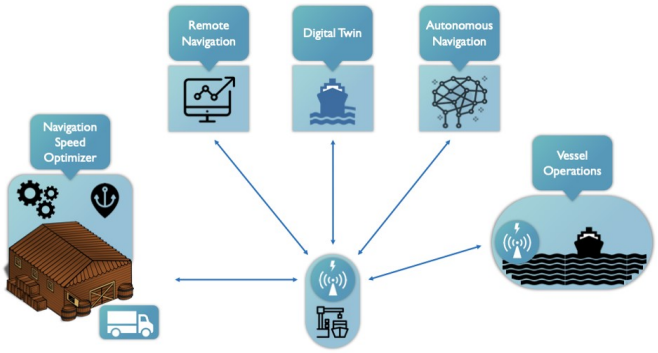

Figure 3: VITAL-5G Antwerp-based use case concept

The ultimate goal of this UC is a) to enhance safety in port area by decreasing incidents more than 10%, b) to reduce dwell time in the port by at least 20%, and c) to reduced vessel captain and ship planning gaps by 25%.

B. Warehouse/freight logistics - Athens facility

The Athens experimentation facility is comprised of the 5G-testbed owned by OTE, the largest Greek MNO, and created in OTE's Athens based research labs for 5G-EVE [10], and the state-of-the-art warehouse / Logistic-hub facilities of DIAKINISIS, the largest 3rd Party Logistics (3PL) Greek operator, located in the suburbs of Athens. The 5G-testbed will be upgraded from its current Non-Stand Alone (NSA) version to 3GPP Rel.16 compliant Stand Alone (SA) and will be interconnected with the DIAKINISIS facilities with fiber connectivity. A 5G small cell will be deployed inside the warehouse providing indoors 5G connectivity, while the already operational 5G network of OTE can be used for outdoors connectivity. Multiple end user devices will be used, such as 5G enabled smartphones/tablets, distributed warehouse sensors and Automated Guided Vehicles (AGVs) to enable the envisioned UC.

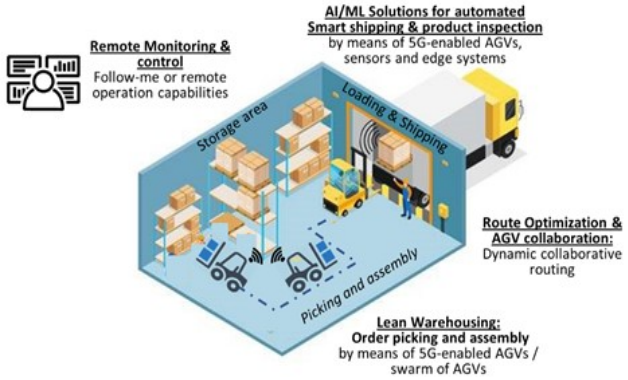

Figure 4: VITAL-5G Athens-based use case concept

The Athens based UC targets the automation and remote operation of freight logistics, effectively instantiating the concept of a *Smart Warehouse*. The target of this UC is to facilitate and optimize day-to-day warehousing operations such as receiving, put-away, picking, checking and shipping, through an integrated state-of-the-art operational system based on AGVs and the easy deployment and control/operation of such services via NetApps. To that end concepts such as *lean warehousing* (elimination of time waste), *in-warehouse route optimization* with obstacle avoidance, *remote surveillance and control*, *human-AGV collaboration, intelligent product inspection* and more, will be addressed in this UC. Furthermore post-shipping truck and product monitoring and control via 5G-enabled on-board sensors will also be investigated. The goal of this UC is to highlight that such advanced functionalities can only be supported via 5G connectivity and to provide a first estimation of the expected performance, while also showcasing the ease of use, flexibility and reduced service deployment times offered by the use of NetApps. Figure 4 depicts the concept of the Athens UC.

C. Data-enaled assisted navigation – Galati (Danube) facility

This UC will be validated over the Romanian 5G testbed which is based on the Orange Romania testbed platform, using parts of the commercial 5G network as well as experimental open source components, created by the 5G-EVE project [10]. The testbed, which is currently a Rel.15 compatible NSA network, will be used during initial experimentation as such, and will be progressively upgraded to a Rel.16 SA network. The upgraded 5G SA infrastructure will be able to support various use case's needs (also for 3rd party experimenters), in terms of KPIs and network requirements and will be enhanced, during the deployment process with orchestration tools, such as ONAP or OSM, automatic services and VNFs onboarding and slicing orchestration. The testbed will also be extended to cover the Galati (Danube) area where trials will take place.

This UC is focused on the implementation of a data-enabled assisted navigation application using IoT sensing system and video cameras installed in Galati port and on a ship and barges (cargos). The implementation is focused on AI/ML mechanisms, IoT, data fusion, ingestion and post-processing which will allow the investigation of concepts, such as fraud detection and sanity checks applied on the sensor data for ship insurance purposes. Through these applications, a safer and more secure port operation will be achieved, regarding the navigation of ships with the help of assisted operation / navigation SW, even in severe weather and water conditions (e.g., shallow waters), while preparations for customs operations and predictive ships / cargo checks may facilitate and speed up loading/unloading operations and customs checks. The ultimate goal of this UC is to achieve a decrease in logistics costs for river-based transportation (up to 15%), a decrease of dangerous navigation events (up to 20%) in river ports, and an increase of the accuracy of the electronic navigation maps used today. Figure 5 depicts the concept of the Danube based use case.

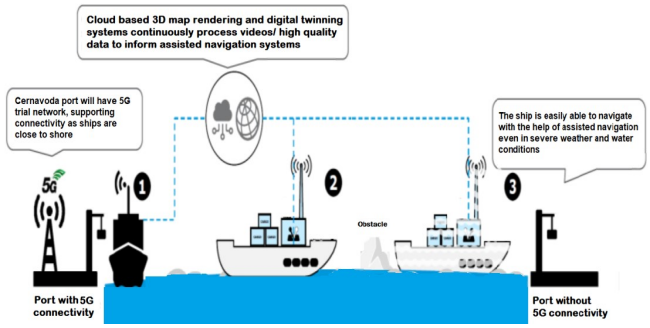

Figure 5: VITAL-5G Danube-based use case concept

D. *Experimentation and Trials*

The NetApps developed within VITAL-5G will be validated in real-life trials that will take place in the three VITAL-5G experimentation facilities addressing the respective use cases, as described in Section III.A-C. Besides this internal experimentation, VITAL-5G will also allow 3rd party experimenters originating from start-ups and SMEs affiliated with the T&L vertical, to make use of the VITAL-5G facilities and to validate their proprietary solutions, offering them access to state-of-the-art experimentation infrastructure that would be otherwise unavailable to them. The experimenters will have the option to either re-use some of the VITAL-5G developed NetApps or to create, on-board and validate their in-house developed NetApps and T&L related applications.

The VITAL-5G platform will support multi-tenancy, meaning that many Experimenters and/or NetApps Developers can access and use it at the same time. Secure and resource-based access control will be implemented to guarantee authorized and accountable access to infrastructure resources through the configuration of appropriate policies and user profiles. Experimenters will use the various functionalities offered by the experimentation tools (dashboards, analytics, etc.) to test, monitor, validate and benchmark the performance of their T&L applications against target KPI values.

IV. TARGETTED INNOVATIONS

VITAL-5G aims to capitalise on recent 5G research by exploiting and developing the results for the T&L vertical, impacting large-scale actors and SMEs active in the T&L ecosystem. The project's innovation map is outlined in Figure 6, where the three main innovation areas, associated ambition and resulting innovations are highlighted. This section provides an overview of the project's innovations and ambitions.

A. *Innovation Area 1: VITAL-5G Service Portal*

VITAL-5G targets the provision of innovative platforms and services to improve effectiveness in how T&L verticals interface with 5G networks. The approach has three areas:

(1) Enhancements to Intent-Based APIs for NetApps: There is a "language gap" between Telecom experts and vertical industries when translating a business goal into a network configuration. VITAL-5G will extend the work carried out in 5G-EVE on intent-based mechanisms and APIs [9] and broaden their applicability to include the T&L vertical.
(2) Platform-agnostic vertical slice design and control for NetApps: 5G Network Slices are being investigated in several standards bodies and within EC-funded projects, resulting in high numbers of network slice information models and associated interoperability problems. This project aims to overcome these issues such that T&L experimenters can design and manage slices transparently by specifying application related requirements through the VITAL-5G Service Portal.
(3) Advanced KPI Analytics & Diagnostics tools for NetApps: KPI validation advances have been significant recently, thanks to the 5G PPP's work on KPI definition and associated industry KPI developments, however, progress in automated KPI diagnostics has been limited. To address this, VITAL-5G will integrate KPI validation tools for service evaluation and benchmarking towards business SLA verification, specifically tailored for the project's T&L use cases.

B. *Innovation Area 2: VITAL-5G facility at T&L sites*

Several facilities are under development that are significant enablers for VITAL-5G, however, their capabilities are insufficient for the needs of the T&L use cases in terms of geographical coverage and availability of edge computing. VITAL-5G plans to reuse assets and extend the 5G-EVE and 5G-Blueprint assets for the benefit of the T&L sector. The project's ambition includes integrating non-ICT-17 5G facilities at the three facilities of Athens, Antwerp and Danube with the VITAL-5G main platform for enhanced coverage at specific T&L sites. To complement this, the project will integrate 5G-connected devices for freight logistics (vessels, robots, AGVs) to validate the benefits of reliable, low-latency 5G connectivity through the T&L-based use cases.

C. *Innovation Area 3: VITAL-5G Open Online Repository & NetApps*

While prior work such as [9][11][12] has produced various catalogues and service portals for 5G/NFV systems, there is high fragmentation in VNF packages and NSD formats/contents. Some additional initiatives are proposing catalogues of 5G functions [13] or, more extensively, catalogues of IoT use cases with references to the related

applications and components [14]. For the T&L sector, support of intelligent applications has been very sporadic, while the adoption of new technologies in terms of 5G-connectivity and network function virtualization has been slow. VITAL-5G will implement a NetApps repository for onboarding packages, with extended role-based access controls. This includes developing vertical specific NetApps supporting the three use cases, described in Section III, that overcome specific T&L sector challenges, as well as vertical-agnostic NetApps focusing on generic application and service monitoring, service testing and message brokering.

D. Resulting Key Ground-Breaking Innovations

Stemming from these three innovation areas that VITAL-5G will explore, the following several innovations will be delivered (see also Figure 6):

- *Innovation Area 1*: i) Highly flexible and powerful vertical NetApps service portal, ii) Comprehensive and production-ready toolkit for T&L NetApps performance evaluation and benchmarking, and iii) New SME-driven 5G orchestration products and service to address the needs of T&L and other vertical markets.
- *Innovation Area 2*: E2E 5G network infrastructure ready for commercialization of innovative T&L services.
- *Innovation Area 3*: Catalogue of NetApps that can support creation of new SME-driven products and service for the T&L market and beyond.

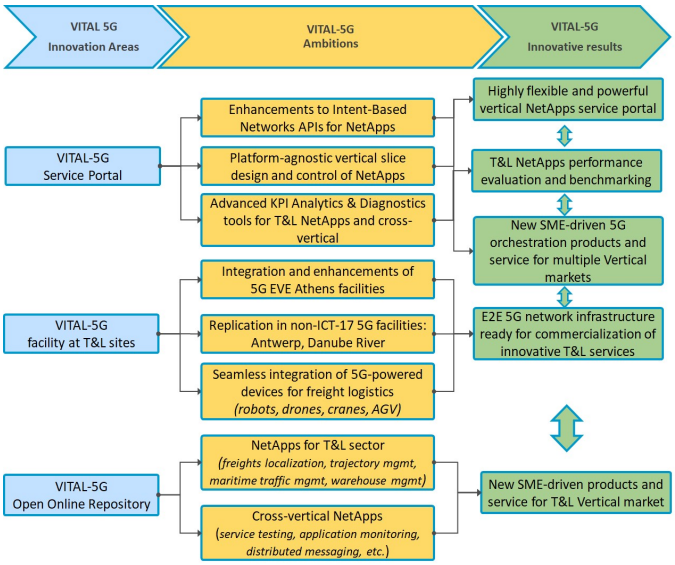

Figure 6: VITAL-5G's innovation map

E. Commercialisation Focus for VITAL-5G's Key Innovations

To ensure VITAL-5G's innovations are orientated towards viable commercial solutions, a focused commercialisation strategy will be adopted. This will entail clearly articulating the market-opportunity associated with those innovations with the highest commercial potential, demonstrating these solutions in the use cases and validating their market-relevance with key commercial stakeholders. The project aims to offer the VITAL-5G Platform and its NetApps as a service to 3rd party experimenters through a joint commercialisation approach with key consortium partners. To support the commercialisation, the project's business plan will be systematically developed using an industry-preferred methodology that ensures innovations are market-aligned, thus accelerating the market impact of the innovations beyond the lifetime of the project.

V. CONCLUIONS

This paper provided an overview of the current challenges, and obstacles that have the potential to slow down the adoption and penetration of 5G-based solutions in the T&L sector and presented the approach of the newly funded VITAL-5G project to address them. VITAL-5G aims to contribute to the minimization of the knowledge/expertise gap between telecom providers, vertical industries and application developers through the promotion and validation of NetApps, over its state-of-the-art experimentation facilities, where cutting-edge technologies and NetApps will be put to the test, as part of T&L industry driven use cases. The project objectives, targeted innovations and developed NetApps, as described in this paper, will contribute to the faster adoption and enhanced penetration rate of more flexible, multi-modal and reconfigurable 5G-based solutions, into the T&L ecosystem.

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